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Managing the risk between historic underground workings and an active open pit using geotextile and SMART markers

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ABSTRACT: Historic underground workings can be a source of unexpected collapse or subsidence of ground when being mined via open pit methods presenting a safety risk to personnel and an economic risk to achieving planned reserves or disruption to the mine plan. Processes for managing these risks in active open pit operations have been developed in many mine sites around the world, however an engineering and monitoring solution for bridging underground workings below permanent haulage ramps in open pit operations has not been well established.

The gold mine in this case study has been mined using both underground and open pit mining methods since its commencement in the 1970's. The current active open pit excavates through extensive historic underground workings. Recently a design constraint was implemented to avoid placing haulage ramps above historic underground working without an engineering and monitoring solution in place. This constraint limited the potential extraction of the mine resource. Several methods were investigated to either engineer out the exposure or change the failure mechanism from brittle to ductile and thus allow for deformation monitoring as a means of risk mitigation. The options selected involved a woven geotextile in combination with RSSI SMART markers as an innovative solution to this unique risk.

The paper discusses the investigation, implementation and ongoing performance of the geotextile and SMART marker system.

1 INTRODUCTION

The gold mine in this case study has been mined using both open pit and underground mining methods at various stages of its life. During open pit mining historic underground workings are exposed in active mining benches posing a unique risk of sudden subsidence/crown pillar collapse to the open pit operation. Void management procedures, including probe drilling, blasting/collapse of working and demarcation of void boundaries are followed to safely mine down through these old workings, however often old works remain below permanent haulage ramps at a predetermined safe cover distance cutback.

Unlike active mining benches which progress vertically at a rapid rate, ramps are generally used for the life of a cutback and sometimes the life of mine. Empirical models for determining adequate rock cover distances often do not take into account exposure period and environment effects such as blasting or rainfall that may trigger crown pillar collapse. These models also did not take into account the unique orientation of the ore body at the mine site and the potential for washing out of pre-existing, uncemented backfill material. This uncertainty in the adequate rock cover distances over a longer period of time led to decision to constrain the mine design by avoiding placing haul routes over workings without an engineering control to limit propagation. This paper presents the engineering and near real time monitoring solution implemented.

2 BACKGROUND AND MINE PLAN

Underground workings were mined along a narrow reef that dipped at between 35 to 40 degrees from horizontal. The underground mining method used at the time was a modified room and pillar method where horizontal ore drives were developed offset to each other along strike of the reef.

Stopes were mined between the drives with pillars left behind at frequent intervals. In some areas with poor rock mass conditions, the main ore drives were hydraulically backfilled using aeolian sand. Declines and level accesses were rarely backfilled. Other areas with good rock mass conditions remained open. As the underground mine was excavated in the 1990's, survey records of the drives and stopes locations were reliable.

The open pit has mined through underground workings at various stages of the mine life. The extent of workings at this mine site is shown in Figure 1.

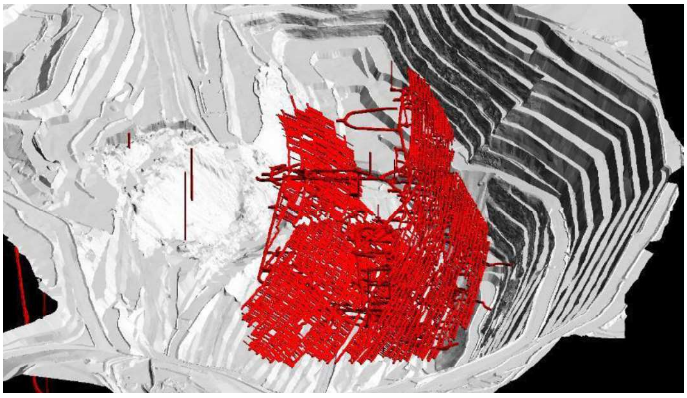


Figure 1. Historic underground workings shown in red against the open pit wireframe.

Void management procedures, such as probe drilling, preconditioning blasting and exclusion zones during excavation activities are practiced. Examples of these void management practices are discussed by Bar et al, 2018. The key gap is how voids interact with critical infrastructure in the open pit, and in this particular case haul road infrastructure. The reason the historic underground workings pose an additional risk where they intersect surface infrastructure are:

- High frequency of vehicles and other mining equipment traversing the area.
- The haul road could be exposed to surface water contributing to the erosion of material within the voids and thus allowing the void to propagate to surface.
- The failure mode where there is a hard crust inter-acting with a void may be brittle (sudden).
- Sudden development of a void on the haul road resulting in equipment suddenly falling into the void and contributing to the person being injured.
- Financial impact associated with delays to the mine sequence while the haul road is being rectified.

In a recent life-of-mine review, several pit design iterations were created. The design with the highest NPV (net present value) included underground workings below the proposed main haulage ramp. How-ever, the design life of the ramp was 5 years. In a site based risk assessment, this design was deemed a higher risk due to the long exposure time. An engineering solution to 'bridge' the gap was required to reduce the risk to an acceptable level to progress with the design.

3 ENGINEERING SOLUTIONS

The primary objective of the engineering solution to bridge areas of underground workings below the main ramp was to mitigate or improve the failure mechanism by ensuring that, if voids are present, the solution will deflect or deform prior to carrying any load by mobilizing a portion of geotextile material strength. Several options were investigated including:

1. Cemented fill
2. Wire rope and mesh sink hole protection system
3. Layered woven geotextile

3.1 Option 1 – Cemented back fill

The proposed cemented backfill was to be placed across the top of the underground workings using crushed aggregate with a 5% cement mix. This product could be manufactured on site using an existing batching plant. Both crushed aggregate and cement products are considered a high cost. With a nominal 1m thick layer, 3100m^3 of cemented fill would be needed. The other key constraint in this process is the use of the cement truck and the long haul required between the batch plant and the placement site. Using the one truck will result in the project taking about 2 months. Due to the costs and estimated timeframe this option was not considered viable.

3.2 Option 2 – Wire rope and mesh sink hole protection system

This commercially available system involved installing a combination of wire mesh and closely spaced tensioned wire rope across the potential void areas. A small team of specialist contractors would be needed to install the system over a period of 2 to 3 weeks. Although this system would have been suitable for this application, the cost for the materials and the specialist contractors made this option not viable.

3.3 Option 3 – Geotextile

The geotextile system would require a section of the ramp to be mined to allow the barrier to be placed and then back filled. From detailed engineering calculations from the supplier and independent consultant it was be shown that the geotextile has sufficient strength to take up the load of a propagating void when placed in two layers and constructed as per the suppliers recommendations.

The geotextile was deemed to be cost effective method considering both total project implementation cost and time-costs related to project implementation time. Tentcate Mirafi PET 1000-50 woven geofabric was used. This was recommended by the supplier and confirmed to be fit for purpose by an external consult-ant.

The benefit of the geofabrics compared to the alternatives included

- Easy of handling using site based equipment
- Ability to install using existing site based civil contractors.
- Relatively low cost

4 PROJECT IMPLEMENTATION

The underground workings remaining below the main ramp are shown in Figure 2. The geofabric and monitoring system (discussed Section Monitoring) was installed above these underground workings. The following construction steps were taken:

- Create an initial pad of suitable fill material 300mm thick across the extent of the planned geofabric installation. Compact to provide a firm base for the first layer of geofabric. The outline is shown in Figure 4.

- Lay the first layer of geofabric material perpendicular to the direction of the underground ore drives and stopes. The geofabric was required to extend pass the edge of the underground workings by at least 6 metres. An overlap of 1m between each rolls of geofabric was also required.

- Place a second layer of fill material over the first layer of geofabric with a 300mm nominal thick-ness

- Place a second layer of geofabric in a direction perpendicular to the first layer. This layer was only required directly above the underground workings (Figure 6).

- Lay a final layer of fill material (300mm thick) over the second layer of geofabric to provide a protective layer during construction of the permanent ramp.

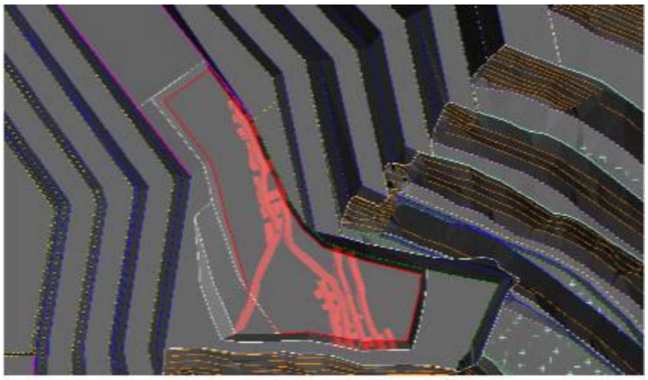


Figure 2. Extent of underground workings shown in red. This area required bridging.

Figure 3. Aerial of the first layer of fill material being placed. Example of the aeolian sand backfill can be seen in the bottom right.

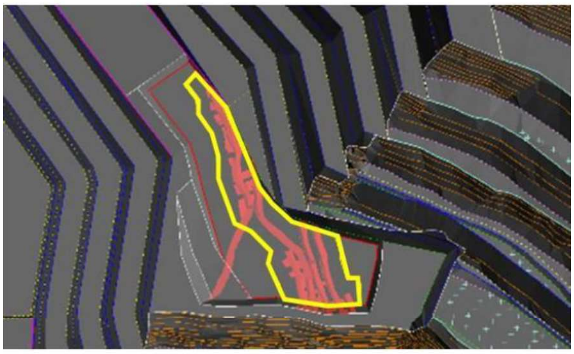


Figure 4. Design outline of the first layer of geofabric in yellow

Figure 5. First layer of geofabric completed.

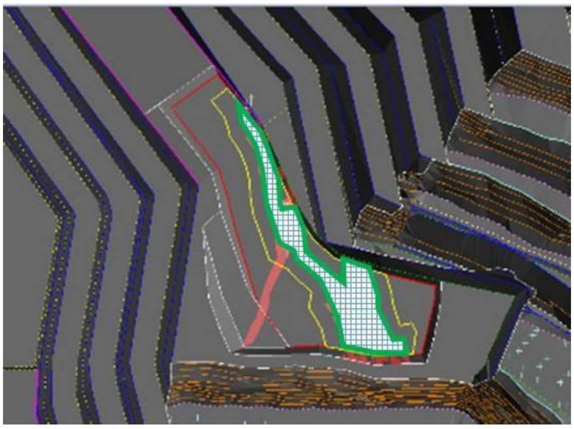


Figure 6. Design outline of the second layer of geof-abric in green.

Figure 7. Second layer of geofabric completed with final layer of fill under construction.

5 MONITORING

Near real time surface and subsurface deformation monitoring of pit slopes is a commonly used and well developed practice (Nicoll et al. 2017; Baczynski & Bar, 2017; Bednarczyk, 2017; Bar et al. 2016). However, technologies for real time monitoring of subsidence across an active haul road are not readily available in the industry. The aim of the monitoring system is to provide warning of subsurface movement (Pfitzner, 2003). The geofabric system installed aimed take up the load of the ramp surface and in doing so deformation in the ramp is possible.

Due to regular traffic of the road surface, conventional surface monitoring tools such as slope stability radar and prism monitoring were not suitable. Subsurface equipment such as extensometers, open hole monitoring, Time Domain Reflectometry (TDR) were also deemed unsuitable. Since the size of the potential voids that could propagate to the surface could be between 2 to 3 metres wide, the aim of the system was to provide a dense coverage to monitor horizontal and vertical displacement in a density that would detect movement at this scale.

A system of 170 networked SMART markers was installed to monitor the area. These markers were initially developed for particle flow tracking in underground caving operations, but have been expanded for use in other applications. The markers are not connected by wires, but communicate via a radio signal with radio strength changes indicating possible movement. The markers also have high precision tilt sensors that can detect small changes in the ramp subsurface due to load taken up by the geofabric caused by propagating void.

This system was linked to a wireless telemetry system with a direct connection to the site monitoring server. The monitoring data can be accessed and analysed to monitor for changes in the ramp conditions over time. This data was incorporated into a trigger action response plan to ensure data was reviewed after subsidence trigger events such as blasting, rainfall and seismic events.

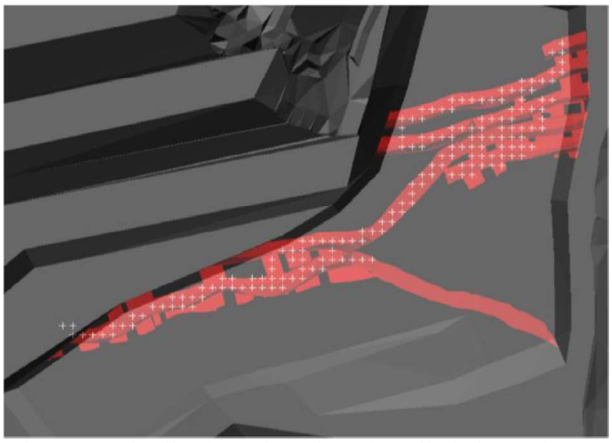
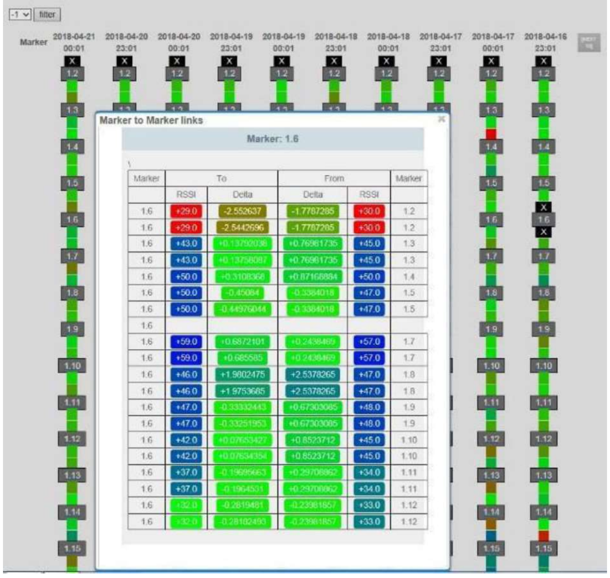


Figure 8. Distribution of markers installed above the geofabric layers

Figure 9. Smart Marker ready for installation



Marker to Marker links

Marker: 1.6

Marker	To		From		Marker
	RSSI	Delta	Delta	RSSI	
1.6	+29.0	-2.552637	-1.7787285	+30.0	1.2
1.6	+29.0	-2.5442696	-1.7787285	+30.0	1.2
1.6	+43.0	+0.13792038	+0.76981735	+45.0	1.3
1.6	+43.0	+0.13758087	+0.76981735	+45.0	1.3
1.6	+50.0	+0.3108368	+0.87166884	+50.0	1.4
1.6	+50.0	-0.45084	-0.3384018	+47.0	1.5
1.6	+50.0	-0.44976044	-0.3384018	+47.0	1.5
1.6					
1.6	+59.0	+0.6872101	+0.2438469	+57.0	1.7
1.6	+59.0	+0.685585	+0.2438469	+57.0	1.7
1.6	+46.0	+1.9802475	+2.5378265	+47.0	1.8
1.6	+46.0	+1.9753685	+2.5378265	+47.0	1.8
1.6	+47.0	-0.33332443	+0.67303085	+48.0	1.9
1.6	+47.0	-0.33251953	+0.67303085	+48.0	1.9
1.6	+42.0	+0.07653427	+0.8523712	+45.0	1.10
1.6	+42.0	+0.07634354	+0.8523712	+45.0	1.10
1.6	+37.0	-0.19695663	+0.29708862	+34.0	1.11
1.6	+37.0	-0.1964531	+0.29708862	+34.0	1.11
1.6	+32.0	-0.2819481	-0.23981857	+33.0	1.12
1.6	+32.0	-0.28182493	-0.23981857	+33.0	1.12

Figure 10. SMART Marker monitoring data

6 CONCLUSIONS

The challenge of open pit mining through underground workings is unique. Processes for mining through underground working in active mining benches are well developed, however engineering solutions for bridging underground workings below permanent open pit haul routes is not well documented. Several options are commercially available for bridging subsidence prone areas, however woven geofabric provided the most effective solution in this case study. Techniques for monitoring subsidence in areas with active traffic provided a challenge for com-mon monitoring equipment, such as slope stability radar and prisms, however network smart markers provided a good alternative to these traditional methods of monitoring.

7 ACKNOWLEDGEMENTS

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